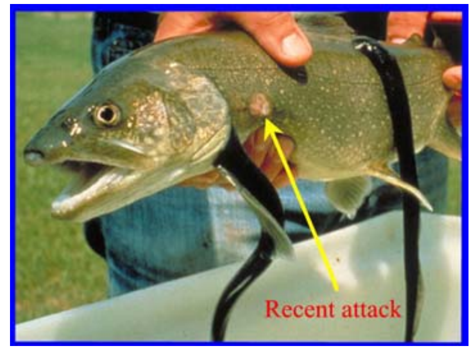
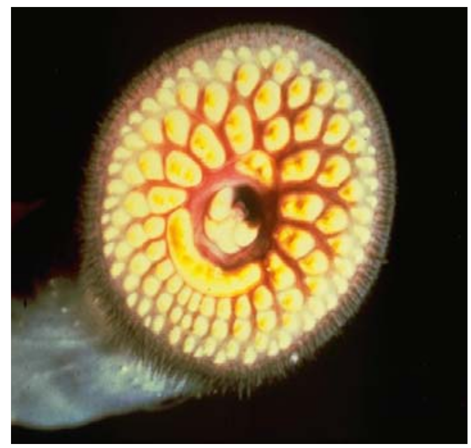
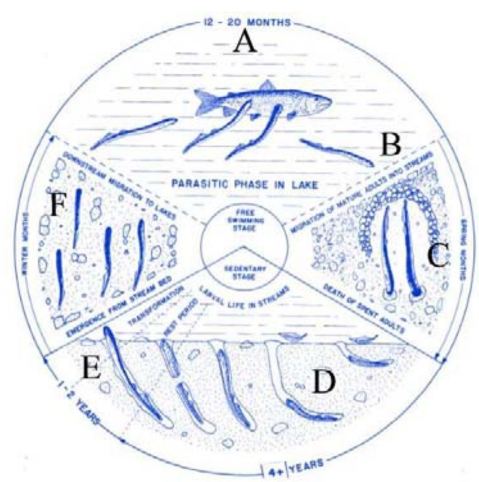
The sea lamprey (*Petromyzon marinus*) is a marine invader from the Atlantic Ocean that entered the Great Lakes through the ship canals and locks built to bypass obstacles like Niagara Falls. An unintended consequence of these canals has been the introduction of invasive species. The sea lamprey was one of the first to invade the Great Lakes. It has been very damaging because part of its life cycle is spent feeding parasitically on the blood of host fish like the native lake trout.



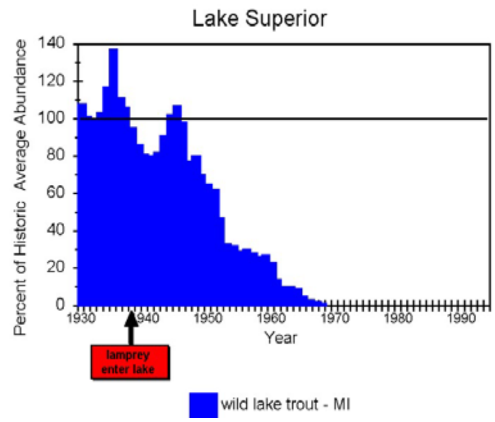
Sea lampreys are a very primitive, jawless fish. In the Great Lakes, people mistakenly referred to them as "eels or lamprey-eels." But, sea lampreys are only very distantly related to eels and are correctly referred to only as "lampreys". Although they are classified as a vertebrate, they lack bones and have only a cartilaginous rod or "notochord" for a spine. The paired fins found on most fish are also absent. The most remarkable feature of the sea lamprey is the tooth-studded oral disk. During the parasitic period of their life cycle, they use the oral disc like a suction cup to attach to the side of a host fish. The many teeth on the rim of the disc provide traction and make it very difficult for a fish to dislodge a sea lamprey. Once attached, they use the teeth on the tongue in the center of the disk to rasp through the skin. An anticoagulant in their saliva maintains blood flow as they feed. Often the host dies from the blood loss. Estimates of the number of pounds of fish killed by each sea lamprey vary from about 15 to 40 pounds.



Fortunately, only one year in the life of a sea lamprey is spent in parasitic feeding. They are unusual in having a complex life cycle, whereas most fish have a simple life cycle. Sea lampreys go through an extended larval phase before metamorphosing into the blood-sucking parasitic phase. Each summer and fall there is one group of parasitic sea lampreys actively feeding in the Great Lakes (A on diagram). The next spring, that group leaves the lake and migrates into tributary streams (B) where they must build nests in clean gravel with flowing water. Each female spawns an average of 60 to 70 thousand eggs (C). After hatch, the larvae drift downstream to areas with slower currents and sand/silt bottoms. There, they establish permanent burrows and enter a larval stage varying in duration from 3 to 10-or-more years (D). Larvae lack eyes and the oral disc. Living concealed in their burrows, they are harmless and filter microscopic material from the water for food. When they reach lengths of 120 mm or more, some individuals begin metamorphosis in mid summer (E). During metamorphosis they develop eyes, the oral disc, and changes in their kidneys that (in their native range) would allow them to enter the salt water of the Atlantic Ocean. That fall or the following spring (F), they instead enter the Great Lakes to feed parasitically on fish that summer and fall, and mature and spawn the next spring—completing their life cycle. Sea lampreys only spawn once and then die after spawning.



Several characteristics of the sea lamprey made it an effective marine invader of the Great Lakes. First, the sea lamprey is an "anadromous" fish. This means that it spawns in fresh water streams, the juvenile phase is spent in salt water in the ocean (or one of the Great Lakes as a substitute), and the adult returns to freshwater streams to spawn. Other anadromous, non-native fish in the Great Lakes include coho salmon, chinook salmon, pink salmon, Atlantic salmon, brown trout, rainbow trout, rainbow smelt, and alewives. Special modifications of their kidneys allows these species to live in either fresh or salt water. If you haven't thought of these species as non-native, they are. Second, sea lampreys produce large numbers of eggs. The Great Lakes contained several smaller, native lampreys, but the sea lamprey rapidly out competed them wherever their range overlapped. Third, we believe that lampreys locate streams for spawning using a pheromone excreted by larvae. This pheromone identifies streams successfully producing young. Because the native lampreys also produced this pheromone, the larger, invading sea lampreys had an effective "road map" for expansion.



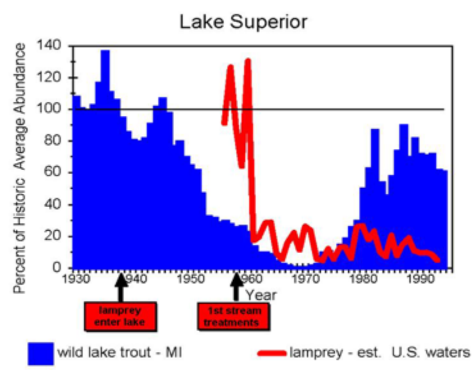
Sea lampreys quickly devastated the fish communities of the Great Lakes. After sea lampreys were discovered above Niagara Falls (in Lake Erie in 1921 and Lake Huron in the early 1930s), they spread throughout the upper Great Lakes by 1939. The lake trout was the main predatory species at that time and the sea lamprey's preferred host. Although early declines in lake trout abundance in the 1940s are suspected to have been caused by overfishing, sea lampreys are believed to be responsible for the very rapid decline in the later 1940s and 1950s. Lake trout actually became extinct in Lakes Ontario, Erie, Huron (except a few inlets of Georgian Bay), and Michigan. Only remnant native stocks remained in Lake Superior. Two factors contributed to the devastating effect of sea lampreys. First, sea lampreys lacked effective predators. Second, the Great Lakes probably have as many miles of tributaries and as many acres of larval habitat as the native range of the sea lamprey along the Atlantic Coast. Yet parasitic-phase sea lampreys produced in Great Lakes tributaries enter the relatively sterile confines of the Great Lakes to feed on small hosts like lake trout instead of entering the Atlantic Ocean to feed on vast numbers of larger hosts like sharks, swordfish, whales, etc.

Other equally important secondary effects were caused by cascading changes in the fish communities. After the elimination of predators like lake trout, the populations of invasive prey species like the rainbow smelt and alewife increased rapidly in the absence of predation. Those invasive species then out competed native species or preyed on their young. Extinctions of sculpin and deepwater cisco species have been suspected of being linked to extended periods of high abundance of smelt and alewives. The massive annual die offs of alewives that fouled the beaches in Michigan during the 1950s and 1960s were due to overcrowding and poor condition and were a secondary effect of the invasion of the sea lamprey. Alewives also prey heavily on zooplankton. Because zooplankton graze on phytoplankton, the density of phytoplankton increased and the color and clarity of water were affected, particularly in the lower Great Lakes.

Human activities were affected first through the loss of sport and commercial fisheries across the Great Lakes. Following those losses, came other, equally important economic effects caused by the disappearance of fishery-related jobs and the loss of fishing tourism. With the beaches fouled with dead alewives, there were also losses of tourism associated with beach use.

The sea lamprey is one of the few aquatic invasive species that is being successfully controlled. In the late 1940s the State of Michigan began investigations into the biology of sea lampreys. In 1950, this became a federal program. In 1955, the Great Lakes Fishery Commission (GLFC) was created under a convention between the United States and Canada for the purpose of restoring fisheries. One of the GLFC's primary duties was the control or eradication of sea lampreys. It currently manages sea lamprey populations across the Great Lakes to about 10% of their former levels. Control is delivered through its control agents, the U.S. Fish and Wildlife Service and the Department of Fisheries and Oceans, Canada. The commission also funds research on sea lampreys at the U.S. Geological Survey's Hammond Bay Biological Station, at Michigan State University, and at the University of Guelph, Ontario.

Control depends on breaking the life cycle. The first control efforts attempted to do that by blocking access to the spawning areas in streams. This was only partially successful because the weirs used to do this were impossible to maintain 100% of the time. There were attempts to use electric fields alone or in conjunction with the weirs, but that was eventually abandoned as too dangerous. A second vulnerable point in the life cycle is during the larval stage, when sea lampreys spend at least three years burrowed in the stream sediment. During the 1950s, over 6,000 chemicals were screened before finding one that was selectively toxic to sea lampreys. That chemical, TFM, has been carefully applied to infested streams, beginning in Lake Superior in 1958. Treatments quickly decreased sea lamprey numbers to 10% or less of their former numbers. Reduced lamprey numbers allowed native and stocked lake trout to survive and the lake trout populations to rebound. Recently, the restoration of lake trout in Lake Superior was declared a success and federal stocking of lake trout was stopped. Lake trout stocks in Lake Superior are once again self-sustaining.



Treatments with TFM start with electrofishing surveys of the Great Lakes tributaries known to potentially produce sea lampreys. Based on estimates of the number of metamorphosed sea lampreys to be produced and on treatment costs, a list of streams to be treated is made each year. Because of the duration of the larval stage, streams are treated at intervals of 3 to 5 years or longer. We now have extensive knowledge of the effect of water chemistry on safe levels of TFM and treatments rarely kill fish. TFM also degrades and does not bioaccumulate. In over 40 years of use there has been no

documentation of accumulation or of long-term effects on streams despite repeated studies with that objective. The return on treatments is the reestablishment of predators and predator/prey balance in the Great Lakes and protection of native species from extinction.

Treatment with TFM is currently still the primary tool for control, but the GLFC, partnered with the Great Lakes Science Center, is committed to providing an integrated program of sea lamprey management in the future that will rely on an increasing number of new control methods. We are now revisiting some of the older concepts such as blocking spawning migration, but using new technologies. Ineffective and labor-intensive screen weirs have been replaced with low-head barriers that block sea lampreys but allow jumping fish to pass. We are also investigating adjustable height barriers that can be lowered after the spawning run, new electrical barriers that use safe levels of pulsed-DC current, and velocity barriers that use the relatively poor swimming ability of sea lampreys to block them but pass other fish.

Our newest control technique is the release of males sterilized by injection with a drug that makes the sperm nonviable. I'll explain the concept with an example. If a stream had a run of 100 sea lampreys (50 males and 50 females) and we trapped 50%, we would catch 25 males and 25 females. Destroying the 25 females would remove 50% of the eggs (potential offspring). If we sterilize the 25 males in a way that does not affect their sex drive and then release them, the sterilized males will compete with the remaining 25 normal males. Eggs from half the remaining females will then not be fertilized, reducing reproduction by another half (bringing it from 50% to 25% of normal). Importing sterilized males from outside the system can drive the percent reduction even lower. We are now applying sterile male release to the last large untreated population in the Great Lakes, the St. Marys River. The St. Marys is the outflow from Lake Superior and is too large to treat with TFM. There, we have done some spot treatments, removing about 50% of the larvae, but are relying primarily on annual trapping of about 50% of the spawners and release of 30 to 50 thousand sterilized males collected from all over the Great Lakes Basin. This results in about a 90% reduction in larvae hatched each year.

Recently, research at the Hammond Bay Biological Station, funded by the GLFC, has produced new knowledge that may lead to other new control methods. We now know the chemical structure of most of the pituitary hormones that regulate sexual maturation (this is known for only a handful of other species). Two pheromones of sea lampreys have also been recently discovered. Pheromones are chemicals released by an animal to the environment that that create a response in others of that species. One (a migratory pheromone) is excreted by larvae and serves to attract adults to suitable spawning streams. We may be able to use this pheromone (or a chemical that would mask it) to direct lampreys to poor spawning streams, to direct them away from good spawning streams, or to attract them to streams that are easy or inexpensive to treat. The other (a sex pheromone) is excreted by spermiated (running-ripe) males and attracts only ovulated females. The sex pheromone may also serve to trigger ovulation in females. Since male sea lampreys start nest construction and then attract females to them, there is a potential for disrupting spawning.

Over the last 20 years, there has been a rapid rise in our knowledge of the basic and molecular biology of sea lampreys and in our ability to measure their populations. Recent increases in GLFC funding for research should accelerate the rate of that rise. The future of control of sea lampreys is promising and is critical to the Great Lakes. The quality of fishing in the Great Lakes and the value of tourism associated with both fishing and our lakeshores are at stake. The cost of sea lamprey control in the U.S. and Canada combined is around $10 million per year. The value of fishing has variously been estimated at $2 to $3 billion—a good return on the investment. The intangible but more important benefit, however, is preserving our native species.